BALTIC COASTAL ZONE
Journal of Ecology and Protection of the Coastline

Vol. 20 pp. 85-99 2016

ISSN 1643-0115

Original research paper

Received: 23/05/2016
Accepted: 26/09/2016

CHANGES OF THE WATER TEMPERATURE IN POLISH SEASIDE RESORTS

Małgorzata Świątek

Hydrography and Water Management Unit,
Faculty of Geoscience, University of Szczecin,
ul. Mickiewicza 16, 70-383 Szczecin, Poland
e-mail: malgorzata.swiatek@usz.edu.pl

Abstract

Subject of the study are changes of the water temperature occurring on the Polish Baltic coast during years 1951-2010 (in Kołobrzeg, due to deficiencies in the data, for the years 1957-2010). It is expressed in the form of a linear trend. The study was based on the monthly average temperature of the sea water in the following stations: Świnoujście, Międzyzdroje, Kołobrzeg, Władysławowo, Hel and Gdynia.

For most of analyzed stations an increase in average annual temperature of the water were observed. The largest one was recorded in Gdynia. In Świnoujście there were no significant changes in water temperature except for the slight its drop in June. A significant increase in the water temperature occurred in Międzyzdroje in February, March, April and May; in Kołobrzeg in January and March; in Władysławowo in January, February, March, April and June and in Hel and Gdynia in February, March, April, May, July and August. The greatest changes were in April in Hel and Gdynia.

Key words: water temperature, air temperature, time trend, Polish Baltic coast

INTRODUCTION

The aim of the study is to check whether the temperature of the sea water on the Polish coast of the Baltic Sea have changed significantly in the years 1951-2010. An additional objective is to verify the consistency of possible trends in water temperature on the coast with changes in air temperature in this region.

The seawater temperature is very important at least because of conditioning the development of the biological life. The increase in temperature causes a reduction in the amount of dissolved oxygen, increasing the biological oxygen demand (BOD) and nitrification accelerating the oxidation of ammonia to nitrate (III) and (V), which in turn leads to oxygen depletion in the water. Significant changes in the seawater temperature have become a big concern for living organisms in the Baltic, forcing them to adapt to new conditions or to limit the size of the population, in extreme cases extinction of the species. The temperature rise is conducive for example to the fast growth of a phytoplankton (Siegel et al. 2008).

Changes in the ecosystem of coastal waters in the southern Baltic Sea area occur mainly during the summer season due to lower river runoff and hence decreased nutrient input. This may result in reduced algae growth in coastal waters but also carries the risk of potentially toxic cyanobacteria blooms. Cyanobacteria growth is also supported by higher water temperatures (Strömer 2011). On the Polish coast massive blooms of cyanobacteria, harmful to humans and animals, are observed when the temperature rises above 20°C. They can occur even at temperatures above 15°C (Mazur and Pliński 2004). Due to the increase of the seawater temperature, the strong growth of biomass of cyanobacteria is forecasted (Hense et al. 2013). Additionally, changes in species composition and distribution, the occurrence of pathogens as well as the introduction of non-indigenous species could be expected due to the warmer water temperature. This changes in the ecosystem are likely to have an effect on anthropogenic uses in coastal waters, like bathing tourism and fisheries (Strömer 2011). Changes in the water temperature, as well as other parameters, especially a salinity, an oxygen content and a transparency, influence on the biodiversity and the size of biological resources of the Baltic Sea. The water temperature also affects the dynamics of the movements of water, heat exchange, momentum and gas exchange between sea and atmosphere (Siegel et al. 2008). Under the investigated scenario (Kjellström et al. 2005) the rise of the sea surface temperature (SST) will lead to an intensified hydrological cycle over the Baltic Sea and will cause the increase of total precipitation in summer over the entire Baltic Sea. The differences in hydrological cycle and precipitation totals concerning not only on the sea, but on surrounding land areas, too (Kjellström et al. 2005**).** Changes in air temperature also affect sea ice cover parameters.

For the purposes of tourism and recreation most valuable is the increase in temperature in summer months. Both water and air temperature in summer are crucial for the development of tourism and recreation in coastal resorts. Then rest on the beach is the most climate-dependent form of recreation (Moreno et al. 2008). Global warming causes an increase in the number of tourists vacationing on the coast in the central and northern Europe (Coombes et al. 2009). Insolation and temperature increase has a positive effect primarily on the number of tourists vacationing on the beaches and taking a marine bath. The improving of conditions conducive to sun bathing and sea baths causes the increase in the number of inhabitants of Central Europe using the resorts in their own country. The increase in the number of tourists coming from neighboring countries is affected by the climatic conditions of the previous year (Falk 2014). On the other hand, social developments like the increasing attractiveness of coastal regions in the southern Baltic Sea area for tourists and migrants will influence the impact on the local ecosystem of coastal waters (Strömer 2011).

The increase in the water temperature in the Baltic Sea refers to the global changes. Analyzes of trends of global surface temperature (Jones and Moberg 2003), taking into account both the temperature of the surface waters of seas and oceans, and land to a depth of 1.5 m of a soil, showed the presence of temperature growth phase since the 1970. On the northern hemisphere the increase was about 0.7°C higher than in the southern one. Since 1990 the increase was more rapid (Siegel et al. 2008).

Changes in average annual and monthly SST in the Baltic Sea during the dozen or twenty years at the turn of the century were analyzed by Siegel et al. (2006, 2008), Bradtke et al. (2010) and Rak and Wieczorek (2012). Changes in the water temperature in the Baltic Sea in a broad term (years 1860-2006) were presented by MacKenzie and Schiedek (2007), in a short one, made on the basis of satellite observations, by Lehmann, Getzlaff and Harlaß (2011). Miętus with the team (Bałtyk jako... 2011) studied the deep water temperature trends, noting its systematic growth. Since 2008 water in the Słupsk Furrow is too warm for the existence of a cod. In the Gotland Deep such situation was to become in 2013. By analyzing changes in water temperature in years 1950-2008 in Władysławowo and Kołobrzeg and in years 1950-1980 in Mielno (Bałtyk jako... 2010) at each of the stations an increase in the mean annual temperature of water was showed.

Changes in the water temperature of the Polish coast examined, among others, Girjatowicz and Chabior (1995). Analysis related to a period from 1947 to 1993. For the analysis they chose Międzyzdroje, Władysławowo and Gdynia. The variability (but not trends) of SST in Polish coast stations were analyzed within the IMGW Research Project KBN 5, as a task 5.4b (Miętus et al. 2003). Long-term changes in seawater temperature in Świnoujście, Międzyzdroje, Puck, Hel and Gdynia as well as their relationships with the air temperature were also reported by Filipiak (2004).

MATERIAL AND METHODS

In the study the monthly average values of the sea surface temperature (SST) from the years 1951-2010 in Świnoujście, Międzyzdroje, Władysławowo, Hel and Gdynia and from the years 1957-2010 in Kołobrzeg were analyzed. The average monthly air temperature values from the years 1951-2010 in Świnoujście, Ustka, Hel, Gdynia and Elbląg from the years 1951-2000 in Kołobrzeg were used, too.

Water temperature were measured daily at a depth of 50 cm. In Świnoujście it was made in the Piast Channel, near the Harbour Master, which means that the results reflect the impact of not only water coming from the Baltic Sea, but also flowing from the Szczecin Lagoon. In Międzyzdroje water temperature was measured at the pier, approximately 20 meters away from the shoreline. In Kołobrzeg at the pier, in a distance of approximately 40 m from the shore and in Władysławowo and Hel at port breakwaters, next to the station gauges. In Gdynia the water temperature was measured next to breakwater at the marina on the outer side of the port basin i.e. on the open waters of the Gulf of Gdańsk.

Time trends were determined using linear regression (linear trend). The statistical significance of the trends at a standard level $\alpha = 0.05$ and additionally at the level of $\alpha = 0.01$ were verified by F test. The F statistic of this test is the ratio of explained variance to unexplained one of dependent variable (here: the water temperature). After comparing the obtained value F with critical value resulting from the F (Fisher) distribution we can determine whether the relationship between two variables (here:

the passage of time and water temperature) is statistically significant (Łomnicki 2000, Rabiej 2012).

In order to better illustrate the changes in air and water temperature, the average decade values of the mean annual temperature were calculated. Decade averages of the water temperature in July and August were calculated and compared, too. This was done because of the importance of tourism and recreation as well as ecological (including the impact on the loss of the vertical circulation of the water and the threat of blooms of cyanobacteria) water temperature in the summer months. In the study average decade water temperature anomalies, called thermal anomalies (i.e., deviation of temperature in a decade from the average temperature throughout considered period on particularly station) have been determined, too.

Before attempting to the implementation of correlation and regression, similarity of the probability distribution of the analyzed variables (average monthly and annual water temperature value) with a normal distribution using the Shapiro-Wilk test were verified. At the level of significance $\alpha = 0.05$, almost all time series data on water temperature gave no reason to reject the null hypothesis of similarity of probability distribution of analyzed variables to the normal distribution. An exception was the temperature of the water in Kołobrzeg and in Władysławowo in August, and Hel in May. Therefore, it was decided to analyze the linear relationship between the passing time and the values of the water temperature, as described by using linear regression. This also applies to the above-mentioned few variables deviating slightly from the normal distribution.

RESULTS

The average annual water temperature is between 8.62°C in Władysławowo to 9.78°C in Świnoujście (Table 1). The air temperature on studied stations is a bit lower, as a result of the possibility of negative values of the air temperature in the winter. The air temperature equals from 7.76°C in Elbląg to 8.42°C in Świnoujście (Table 2). Tables 1 and 2 represent the average monthly and yearly temperature of the water (Table 1) and the air (Table 2).

The average annual temperature of the water in Międzyzdroje, Władysławowo, Hel and Gdynia increases statistically significant (Fig. 1, Table 3), although this rise is not big (of the order of 0.10-0.18°C for 10 years). In Świnoujście and Kołobrzeg significant changes did not occur. In Gdynia, the water temperature increased the most, an average of about 0.018°C $year^{-1}$.

Analysis of average monthly values demonstrated statistically significant (at the level of $\alpha = 0.05$) increase in the water temperature occurred in Międzyzdroje in February, March, April and May; in Kołobrzeg in January and March (the period under review: 1957-2010); in Władysławowo in January, February, March, April and in June; in Hel and Gdynia in February, March, April, May, July and August (Table 3). In Świnoujście there was no significant change in temperature with the exception of a slight decrease in water temperature in June. In the autumn months and in December no significant changes in water temperature were observed on any of the analyzed stations (Table 3).

Table 1

Average monthly and yearly values of the water temperature (°C) in Polish seaside resorts (1951-2010, Kołobrzeg: 1957-2010)

	Świnoujście	Międzyzdroje	Kołobrzeg	Władysławowo	Hel	Gdynia
Jan.	1.25	1.18	1.63	1.42	2.05	1.70
Feb.	1.20	1.05	1.44	1.19	1.44	1.22
Mar.	2.70	2.69	2.74	2.45	2.23	2.20
Apr.	7.33	6.55	6.29	5.75	5.00	5.72
May	13.12	11.60	10.54	9.52	9.37	10.75
June	17.16	16.24	14.67	13.47	13.96	15.06
July	19.12	18.55	17.57	17.18	17.53	18.12
Aug.	19.27	18.72	17.50	17.41	18.50	18.96
Sep.	16.10	15.78	15.15	14.83	15.96	15.87
Oct.	11.32	11.19	11.07	10.56	11.90	11.47
Nov.	6.15	6.33	6.78	6.37	7.54	6.68
Dec.	2.62	2.79	3.35	3.16	4.09	3.43
Year	9.78	9.39	9.06	8.62	9.14	9.28

Table 2

Average monthly and yearly values of the air temperature (°C) in Polish seaside resorts (1951-2010, Kołobrzeg: 1951-2000)

	Świnoujście	Kołobrzeg	Ustka	Hel	Gdynia	Elbląg
Jan.	-0.12	-0.36	-0.33	-0.26	-0.20	-2.11
Feb.	0.31	-0.16	-0.13	-0.33	-0.10	-1.49
Mar.	2.93	2.45	2.28	1.82	2.28	1.94
Apr.	6.74	6.14	5.90	5.57	6.04	7.18
May	11.45	10.65	10.40	10.43	10.95	12.29
June	15.32	14.59	14.33	14.75	15.19	15.82
July	17.44	16.83	16.96	17.32	17.59	17.56
Aug.	17.29	16.71	16.92	17.37	17.60	17.21
Sep.	13.94	13.51	13.66	13.94	14.04	13.24
Oct.	9.44	9.28	9.36	9.55	9.56	8.52
Nov.	4.68	4.43	4.68	4.84	4.81	3.48
Dec.	1.35	1.20	1.27	1.54	1.52	-0.26
Year	8.42	7.97	7.97	8.07	8.30	7.76

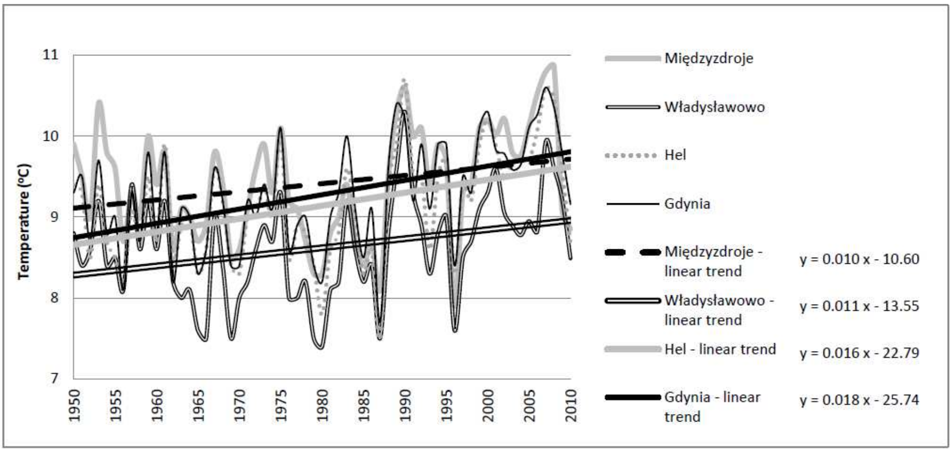

Fig. 1. Long-term variability of annual average water temperature together with its linear trend in Polish seaside resorts (1951-2010, Kołobrzeg: 1957-2010) all tends are statistical significant on level α = 0.05

Table 3

Linear trends (°C year^{-1}) of changes of water temperature in Polish seaside resorts (1951-2010, Kołobrzeg: 1957-2010)

	Świnoujście	Międzyzdroje	Kołobrzeg	Władysła-wowo	Hel	Gdynia
Jan.	0.006	0.011	**0.027***	**0.018**	0.014	0.012
Feb.	0.007	**0.017**	0.019	**0.017**	**0.020***	**0.015**
Mar.	0.007	**0.026**	**0.023**	**0.021**	**0.027***	**0.027***
Apr.	0.014	**0.024***	0.007	**0.017**	**0.030***	**0.037***
May	0.004	**0.030***	0.007	0.012	**0.035***	**0.043***
June	**-0.017**	0.009	0.014	**0.018**	0.014	0.014
July	-0.008	0.011	-0.008	0.005	**0.023***	**0.032***
Aug.	0.006	0.012	0.007	0.011	**0.019**	**0.026***
Sep.	-0.007	-0.007	-0.012	0.000	0.012	0.013
Oct.	-0.008	-0.013	-0.014	-0.005	0.001	-0.002
Nov.	-0.002	-0.008	0.013	0.007	0.000	-0.006
Dec.	-0.003	-0.002	0.016	0.010	0.004	-0.001
Year	-0.000	**0.010**	0.008	**0.011***	**0.016***	**0.018***

statistically significant at α = 0.05 bolded
* statistically significant at α = 0.01

Table 4
Linear trends (°C year^{-1}) of changes of air temperature in Polish seaside resorts (1951-2010, Kołobrzeg: 1951-2000)

	Świnoujście	Kołobrzeg	Ustka	Hel	Gdynia	Elbląg
Jan.	0.022	0.041	0.032	0.025	0.031	
Feb.	**0.050**	**0.067**	**0.055***	**0.043**	**0.050**	**0.055**
Mar.	**0.038***	**0.057***	**0.043***	**0.036***	**0.040***	**0.044***
Apr.	**0.035***	**0.041***	**0.037***	**0.033***	**0.030***	**0.040***
May	**0.030***	**0.042***	**0.031***	**0.039***	**0.036***	**0.031**
June	0.007	0.018	0.012	0.006	0.006	0.027
July	**0.025**	0.017	**0.033***	**0.023**	**0.023**	**0.026**
Aug.	**0.026***	**0.027***	**0.031***	**0.020**	**0.023***	**0.026**
Sep.	0.013	0.002	0.017	0.012	0.012	0.011
Oct.	-0.002	0.010	0.009	-0.002	-0.002	-0.004
Nov.	0.005	-0.003	0.015	0.008	0.008	0.007
Dec.	-0.002	0.008	0.009	0.007	0.007	0.004
Year	**0.020***	**0.027***	**0.027***	**0.019***	**0.022***	**0.023***

statistically significant at α = 0.05 bolded
* statistically significant at α = 0.01

Changes in the water temperature refer to changes in the air temperature (Table 4). However, while air temperature changes in the all analyzed stations are similar, the changes of temperature of the water are various. The thermals of water of the southern Baltic coast are affected by factors related to the local circulation of water which disruptors general trends of temperature.
The value of the average annual air temperature increased statistical significantly in all of the analyzed stations (Świnoujście, Kołobrzeg, Ustka, Hel, Gdynia and Elbląg). This increase ranged from 0.19°C in each 10 years in Hel to 0.27°C per 10 years in Kołobrzeg and Ustka (Table 4).
For the all analyzed stations (Świnoujście, Kołobrzeg, Ustka, Hel, Gdynia and Elbląg) an increase of the air temperature in February, March, April, May, July (except Kołobrzeg) and in August has been observed. For reasons of tourism and recreation, the most important temperature increases (both air and water ones) were in the summer months. Water temperature rise during the summer months only at stations located on the Bay of Gdańsk – Hel and Gdynia. These are not changes that significantly impact the growth of the tourist attractiveness of the region. The average monthly water temperature rise over the 60 analyzed years has reached from 1.3°C in August in Hel to 2°C in July in Gdynia.
The greatest convergence of the air and the water temperature was observed in Hel and Gdynia. In both of these stations, the slopes of the equations of the trend lines are significant in the same months (February, March, April, May, July and August)

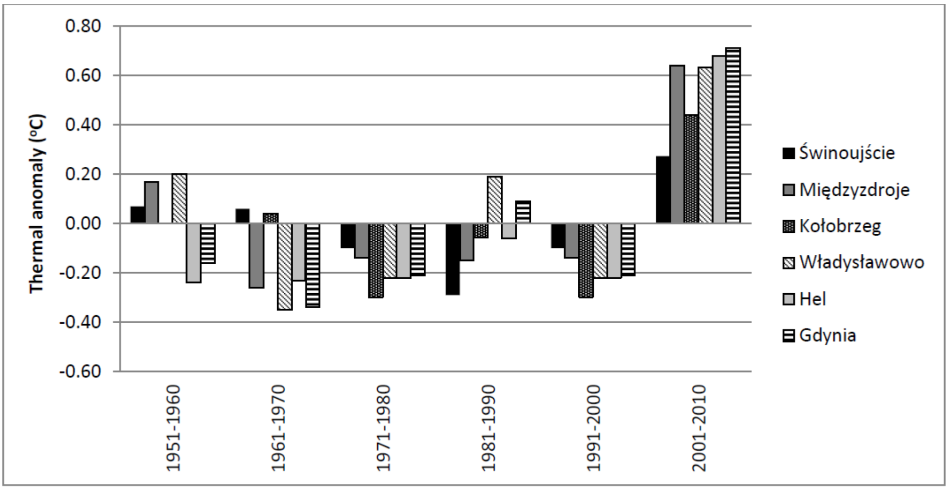

Fig. 2. Deviations (°C) of annual average water temperature in different decades from the long-term average (thermal anomaly) in Polish seaside resorts (1951-2010, Kołobrzeg: 1957-2010)

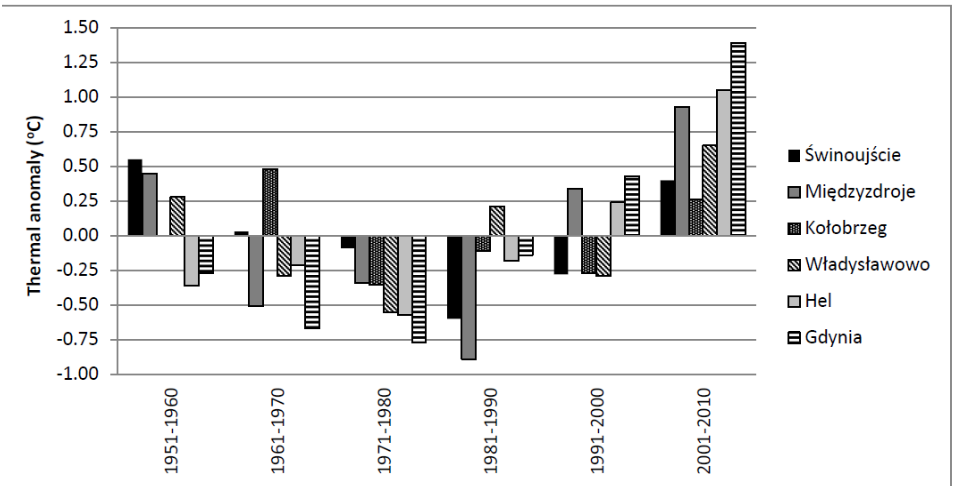

Fig. 3. Deviations (°C) of average water temperature in July in different decades from the long-term average (thermal anomaly) in Polish seaside resorts (1951-2010, Kołobrzeg: 1957-2010)

and even they have similar values (Table 3 and Table 4). The biggest changes in both the water temperature and the air one occurred in spring, strictly in April and May. Values of regression coefficients in Hel and Gdynia in April and May amounted from 0.03 to 0.043 in the case of water temperature (Table 3) and from 0.03 to 0.04 in the case of the air one (Table 4).

Lack of statistically significant trends within the all considered period (60 years) does not mean that the water temperature is not higher than in the second half of the twentieth century. Analysis of the average temperature values in various decades has shown that both the annual water temperature (Fig. 2) and the air one, first decade of the twenty-first century was higher than in each of the decades of the second half of the twentieth century. In the aim of better illustrate the differences between successive decades Figure 2 shows the thermal anomalies (deviation of temperature in particularly decades from the long-term average value) consecutive decades.

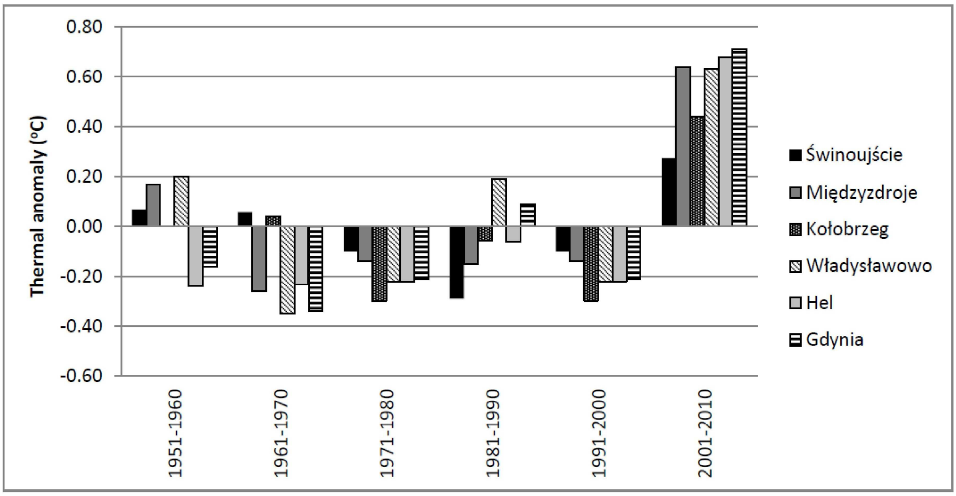

Fig. 4. Deviations (°C) of annual average water temperature in August in different decades from the long-term average (thermal anomaly) in Polish seaside resorts (1951-2010, Kołobrzeg: 1957-2010)

In July, at most of stations (in Międzyzdroje, Władysławowo, Hel and Gdynia), the average decade temperature of water in the first decade of the twenty-first century were higher than in each of the decades of the second half of the twentieth century. Simultaneously at each station the water temperature in the years 2001-2010 was higher than the average for the entire period 1951-2010. Average decade water temperature in August for each station in the first decade of the twenty-first century were higher than each of the second decades of the twentieth century. The difference between the temperature of the water in different decades are shown in Figures 3 (July) and 4 (August) in the form of thermal anomalies.

DISCUSSION

When interpreting the results of the analysis, one must take into account, that the water temperature in Świnoujście showed different long-term variability than on other stations due to the placement of the measuring point at the mouth of Świna. Therefore the measurement of the water temperature in Świnoujście is affected by the water temperature of Oder river and Szczecin Lagoon, more even than the temperature of the Baltic Sea water. Consequently the main factor influencing the temperature in this station was atmospheric circulation and the associated surface wind direction. It influenced the direction of flow of water – inflow of the water from the sea or from the Szczecin Lagoon.

Most likely differences between changes in the air and water temperature are caused by the occurrence of specific vertical circulation of coastal waters. In these parts of the coast, where the sea circulation is stronger, changes in air and water temperature does not proceed synchronously. Overall, on the Baltic Sea the regions with lower correlation between the air and sea-surface temperature are dynamically the most active, with the highest annual average current velocities and highly stable circulation (Bradtke et al. 2010).

Specific long-term water temperature variability in Kołobrzeg are caused by the occurrence of upwelling in this region (Krężel et al. 2005; Kowalewski and Ostrowski 2005), which is a result of the bathymetry of the seabed (relatively large depth of the basin). This phenomena may also appear nearby Władysławowo. Unless, however, the incidence of upwelling in Władysławowo is decreasing, it is increasing in Kołobrzeg (Lehmann et al. 2012). These trends are not without effect on the changes in the temperature of the water in the warm half of a year, when there are much greater vertical thermal gradients in the seawater than in the cool half of a year. In the years 1990-2009 decline in turnout occurrence of upwelling along the Polish Baltic coast was observed (Omstedt et al. 2014), which contributed to the increase in average temperature of coastal water in the warm half of a year. This is a result of changes in the atmospheric circulation, because the occurrence of upwelling on the Polish coast is closely connected with the inflow of air masses from the east and south-east (Jankowski 2000).

The increase in water temperature in the Polish seaside resorts, demonstrated in this work, have been confirmed to some extent by other studies. The research conducted by Rak and Wieczorek (2012) showed that in the period from 1998 to 2010 nearby the Polish Baltic coast, exactly in Bornholm Basin, Słupsk Farrow and Gdańsk Basin the increase in water temperatures was observed, especially in the case of surface water (0.11°C year^{-1}) and the bottom one (0.16°C year^{-1}). Analysis of trends of water temperatures at coastal stations in the years 1950-1993 carried out by Girjatowicz and Chabior (1995) revealed that during periods of low water temperature, which is in winter and spring, the sea surface temperature (SST) shows an upward trend. There are statistically significant trends of SST only in the spring in Gdynia and in the winter in Władysławowo. During the period of high values of SST, i.e. during the summer and autumn, the SST showed decreasing trends. A statistically significant linear trend was observed in the autumn in Międzyzdroje. Trends of the average annual SST were not clear and statistically insignificant.

According to Filipiak (2004), the average annual value of SST on the Polish coastal stations showed in the second half of the twentieth century a slight increase ranging from 0.2°C to 0.35°C. The increase in SST in the spring was significant - amounted to 1°C in Międzyzdroje, Świnoujście and Hel and 1.5°C in Puck and Gdynia. In summer, the increase was lower, although it reached 1°C in Gdynia and Puck. In the winter it equal only 0.2°C. In the autumn there was a decrease of SST, this decline reached 0.7-0.8°C at particular stations. Filipiak (2004) correlated SST and the air temperature, too. He showed that the strongest relationships occurred over the Bay of Gdańsk, taking into account the seasons, the strongest correlations were in summer.

The results of research on the SST of waters located far from a shore and analyzed in somewhat shorter time-series data than in the paper, present different results than these relating to coastal waters presented in the study. The analysis performed for the period 1985-2005 in Arkona Basin and Gotland Basin (Siegel et al. 2008) showed the largest increases of SST in August and September and in May and October. The increase in the annual average water temperature in the Baltic Sea at that time amounted to approx. 1°C. Analysis carried out in 1990-2004 (Siegel et al. 2006) showed weak positive trend in the mean water temperature in the entire Baltic Sea. The slopes of linear trends showed slight negative trends, particularly in the winter months of February and March. Strong positive trends occurred in the summer months of July and August but also in September and October.

According to Lepparänta and Myrberg (2009) in all basins of the Baltic Sea water temperature increased in the period 1900-1980. According to Neumann and Friedland (2011), the largest increase in surface water temperature in the Baltic Sea was recorded during the summer, while in autumn and spring were lower. Two-decadal trends of monthly SST in the Baltic Sea show also that warming occurs mainly in the summer months. Statistically significant trends were found for almost the whole Baltic Sea in August and September (Bradtke et al. 2010). The analysis of changes in the Baltic Sea water temperatures from the 60s. of nineteenth century (MacKenzie and Schiedek 2007) showed a statistically significant rise of SST in Central Baltic in all seasons. The largest one was in the summer, comparable to the increase in average annual SST. In Bornholm Basin at the same time (from 1860. to the beginning of 21st century), seasonal values of SST did not change significantly, but changes of the mean annual SST were significant. Löptien and Meier (2011) showed the potential of increasing water turbidity to influence summer SST in the Baltic Sea and corresponding trends significantly. A local increasing water turbidity seems likely while close to the coast this effect might be more than doubled.

Changes in the water temperature are highly correlated with the increase in air temperature. In the Baltic Sea Basin the biggest changes in air temperature were observed in the spring, esp. since 1956 (Heino et al. 2008). The increase in air temperature on the Baltic Sea, particularly strong in the years 1985-2000, was influenced by an increase in the frequency of anticyclonic atmospheric circulation and the western air flow (Omstedt et al. 2004). Research conducted by the project CLIMATE (Biernacik et al. 2010) confirmed that the main baric system influencing the change in mean air temperature in the analyzed region is the North Atlantic Oscillation controlling the intensity of the zonal flow of air masses.

The positive trend in air temperature in the Baltic Sea Basin was largely the result of anthropogenic increase in greenhouse gas emissions and their concentrations in the atmosphere (Heino et al. 2008) According to Neumann and Friedland (2011) anthropogenic factors are the main cause of thermal changes taking place within the Baltic Sea region. Weaker response of SST to global warming in winter can be explained by the increased thickness of the mixed homogenous surface layer in comparison to the summer and by the additional heat supply required to melt the sea ice before water column can start to warm up (Meier 2006), so in the central part of the Baltic Sea data analyzed even showed negative trends in winter months (Bradtke et al. 2010). In addition, in winter on ice-free sea areas evaporative heat loss are increasing, affecting in water temperature.

Surface water temperature, especially in semi-enclosed shallow coastal waters, may be associated with changes in cloud cover in the area. Although research on changes in cloud cover (Miętus et al. 2003) did not confirm a significant decrease in cloud cover on the Polish coast, Koźmiński and Michalska (2004) showed an increase in the average sunshine in Pomerania in May, June, in the both half-years (the cold and the warm ones) and in the year.

According to many researchers, positive trends in air temperature will be continued. It is believed that the increase in air temperature in the entire 21st century will be from 3 to 5°C (Neumann and Friedland 2011). This fact along with other factors, will contribute to a further increase in water temperature in the Baltic Sea. It is expected that in the twenty-first century it will be from 2 to 3.5°C (Neumann and Friedland 2011). Models of the relationship between climate change and fish resources (MacKenzie et al. 2012) suggest increase in the biomass and expected fishery yields under sustainable exploitation. The present paper proves that changes in air temperature and water temperature do not extend in the parallel manner. Reported changes in air temperature affected changes in water temperature (SST) in a fact, but not in the same way at each station. Relationships between air and water temperature variability can be trace by a comparison of the data presented in the tables.

CONCLUSIONS

The presented results of the work indicate an increase in the water temperature in the first decade of the twentieth century in relation to the second half of the twentieth century in the Polish seaside resorts. Especially, it is clearly evident in the case of average annual temperatures and temperatures in the spring months, when there were increases in water temperature in most of the analyzed stations documented by statistically significant linear trends. Even in periods and months in which no relevant trends were demonstrated, the water temperature in the period 2001-2010 were higher than in the individual decades of the second half of the twentieth century.

The paper proves positive trends of air temperature, although they were diverse, both spatially and temporally (seasonal). They concern the annual values as well as monthly values in months from February to May inclusive, in July (at most stations), and in August. In the remaining months, no significant trends in any of the analyzed stations were detected. The increase in water temperature was not so clear and uniform for the whole area as the increase in air temperature due to local conditions (mainly circular) that affect the water temperature. The SST along the Polish Baltic coast is also influenced by water from other parts of the sea mixing with coastal waters so water temperature rises in fact but not as much as the air temperature in the same places.

REFERENCES

Biernacik D., Filipiak J., Miętus M., Wójcik R., 2010. Zmienność warunków termicznych w Polsce po roku 1951. Rezultaty projektu KLIMAT. W: Klimat Polski na tle klimatu Europy. Zmiany i konsekwencje. (The variability of thermal conditions in Poland since 1951. The results of KLIMAT research project. In: Polish climate on the Europe's climate background. Changes and their consequences). (Ed.) E. Bednorz, L. Kolendowicz, Bogucki Wydawnictwo Naukowe, Poznań, 5-18, (in Polish).

Bradtke K., Herman A., Urbański J., 2010. Spatial and interannual variations of seasonal sea surface temperature patterns in the Baltic Sea. *Oceanol.*, 52, 345-362.

Bałtyk jako element systemu klimatycznego i jego rola w tworzeniu się stanów zagrożenia. Sprawozdanie z okresu I 2009 – XII 2009. (The Baltic Sea as a part of the climate system and its role in the formation of emergencies. A report from the period of January 2009 – December 2009), 2010. (Ed.) M. Miętus, IMGW, Gdynia, (in Polish).

Bałtyk jako element systemu klimatycznego i jego rola w tworzeniu się stanów zagrożenia. Sprawozdanie z okresu I 2010 – XII 2010. (The Baltic Sea as a part of the climate system and its role in the formation of emergencies. A report from the period of January 2010 – December 2010), 2011. (Ed.) M. Miętus, IMGW, Gdynia, (in Polish).

Coombes E., Jones A., Sutherland W., 2009. The implications of climate change on coastal visitor numbers: a regional analysis. *J. Coast. Res.*, 25(4), 981-990.

Falk M., 2014. Impact of weather conditions on tourism demand in the peak summer season over the last 50 years. *Tourism Man. Persp.*, 9, 24-35.

Filipiak J., 2004. Zmienność temperatury powietrza na Wybrzeżu i Pojezierzu Pomorskim w drugiej połowie XX wieku. (Variability of air temperature on the coast and the Pomeranian Lake District in the second half of the twentieth century). IMGW, Warszawa, (in Polish).

Girjatowicz J., Chabior M., 1995. Trendy i cykle temperatury wody u polskiego wybrzeża Bałtyku. (Trends and cycles of water temperature at the Polish Baltic coast). *Inż. Mors. i Geotech.*, 4, 162-165, (in Polish).

Heino R., Toumenvirta H., Vuglinsky V., Gustafsson B., Alexandersson H., Bäring L., Briede A., Cappelen J., Deilang C., Falarz M., Førland E., Haapala J., Jaagus J., Kitajev L., Konl A., Kuusist E., Lindström G., Meier M., Miętus M., Moberg A., Myrberg K., Niedźwiedź T., Nordli Ø., Omstedt A., Orviku K., Pruszak Z., Rimkus E., Russak V., Schrum C., Smursaar Ü., Vihma T., Weisse R., Wibig J., 2008. Past and current climate change. In: the BACC Author Team, Assessment of climate change for the Baltic Sea Basin. Springer-Verlag, Berlin-Heidelberg, 45-132.

Hense I., Meier M., Sonntag S., 2013. Projected climate change impact on Baltic Sea cyanobacteria. *Clim. Change*, 119, 391-406.

Jankowski A., 2000. Wind-induced variability of hydrological parameters in the coastal zone of the southern Baltic Sea – a numerical study. *Oceanol. Stud.*, 3, 5-34.

Jones P.D., Moberg A., 2003. Hemispheric and large-scale surface air temperature variations: an extensive revision and an update to 2001. *J. Clim.*, 16, 206-223.

Kjellström E., Döscher R., Meier M., 2005. Atmospheric response to different sea surface temperatures in the Baltic Sea: coupled versus uncoupled regional climate model experiments. *Nordic Hydrol.*, 36, 397-409.

Kowalewski M., Ostrowski M., 2005. Coastal up- and downwelling in the southern Baltic. *Oceanol.*, 47 (4), 435-475.

Koźmiński C., Michalska B., 2004. Atlas zasobów i zagrożeń klimatycznych Pomorza. (Atlas of climatic resources and hazards in Pomerania). University of Agriculture in Szczecin, (in Polish).

Krężel A., Ostrowski M., Szymelfeing M., 2005. Sea surface temperature distribution during upwelling along Polish Baltic coast. *Oceanol.*, 47 (4), 415-432.

Lehmann A., Getzlaff K., Harlass J., 2011. Detailed assessment of climate variability in the Baltic Sea area for the period 1958 to 2009. *Clim. Res.*, 46, 185-196.
Lehmann A., Myrberg K., Hoflich K., 2012. A statistical approach to coastal upwelling in the Baltic Sea based on the analysis of satellite data for 1990-2009. *Oceanol.*, 54 (3), 369-393.
Leppäranta M., Myrberg K., 2009. Physical Oceanography of the Baltic Sea. Springer, Berlin.
Löptien U., Meier M., 2011. The influence of increasing water turbidity on the surface temperature in the Baltic Sea: a model sensitivity study. *J. Mar. Sys.*, 88, 323-331.
Łomnicki A., 2000. Wprowadzenie do statystyki dla przyrodników. (Introduction to statistics for naturalists). PWN, Warszawa, (in Polish).
Mackenzie B., Schiedek D., 2007. Daily ocean monitoring since the 1860s shows record warming of northern European seas. *Glob. Change Biol.*, 13, 1335-1347.
Mackenzie B., Meier M., Lindegren M., Neuenfeldt S., Eero M., Blenckner T., Tomczak M., Niiranen S., 2012. Impact of climate change on fish population dynamics in the Baltic Sea: a dynamical downscaling investigation. *AMBIO*, 41, 626-636.
Mazur H., Pliński M., 2004. Zakwity toksycznych gatunków cyjanobakterii w Zatoce Gdańskiej. W: Środowisko polskiej strefy brzegowej południowego Bałtyku – stan obecny i przewidywane zmiany w przededniu integracji europejskiej. (Blooms of toxic species of cyanobacteria in the Gulf of Gdańsk. In: Environment of the Polish coastal zone of the southern Baltic – current status and expected changes on the eve of European integration). (Ed.) J. Cyberski, GTN, Gdańsk, 113-124, (in Polish).
Meier M., 2006. Baltic Sea climate in the late twenty-first century: a dynamical downscalling approach using two global models and two emission scenarios. *Clim. Dynamics*, 27, 39-68.
Miętus M., Filipiak J., Owczarek M., Jakusik E., 2003. Ocena zmian procesów meteorologicznych, hydrologicznych i chemicznych zachodzących w środowisku morskim południowego Bałtyku oraz na terenach przybrzeżnych. (Assessment of changes of the meteorological, hydrological and chemical processes in the marine environment of the Baltic Sea and the southern coastal areas). IMGW, Gdynia.
Moreno A., Amelung B., Santamarta L., 2008. Linking beach recreation to weather conditions: a case study in Zandvoort, Netherlands. *Tourism in Mar. Env.*, 5 (2-3), 111-120.
Neumann T., Friedland R., 2011. Climate change impacts on the Baltic Sea. In: Global change and Baltic coastal zones. (Eds) G. Schernewski, J. Hofstede, T. Neumann, Springer, Berlin, 51-70.
Omstedt A., Pettersen C., Rodhe J., Winsor P., 2004. Baltic Sea climate: 200yr of data air temperature, ice cover, and atmospheric circulation. *Clim. Res.*, 25, 205-216.
Omstedt A., Elken J., Lehmann A., Leppäranta M., Meier H.E.M., Myrberg K., Rutgersson A., 2014. Progress in physical oceanography of the Baltic Sea during 2003-2014 period. *Progr. in Oceanogr.*, 128, 139-171.
Rabiej M., 2012. Statystyka z programem *Statistica*. (Statistics with the program *Statistica).* Helion, Gliwice, (in Polish).
Rak D., Wieczorek P., 2012. Variability of temperature and salinity over the last decade in selected regions of the Southern Baltic Sea. *Oceanol.*, 54 (3), 339-354.
Siegel H., Gerth M., Tschersich G., 2006. Sea surface temperature development of the Baltic Sea in the period 1990-2004. *Oceanol.*, 48, 119-131.
Siegel H., Gerth M., Tschersich G., 2008. Satellite-Derived Sea Surface Temperature for the Period 1990-2005. In: State and Evolution of the Baltic Sea, 1952-2005: A Detailed 50-Year Survey of Meteorology and Climate, Physics, Chemistry, Biology, and Marine Environment. (Eds) R. Feistel, G. Nausch, N. Wasmund, A John Wiley & Sons, Inc., Hobocen, 241-263.

Strömer O., 2011. Climate change of impacts on coastal waters of the Baltic Sea. In: Global change and Baltic coastal zones. (Eds) G. Schernewski, J. Hofstede, T. Neumann, Springer, Berlin, 51-70.

ZMIANY TEMPERATURY WODY W POLSKICH MIEJSCOWOŚCIACH NADMORSKICH

Streszczenie

Przedmiot badań stanowią zmiany temperatury wody zachodzące na polskim wybrzeżu Bałtyku w latach 1951-2010 (w Kołobrzegu ze względu na braki w danych w latach 1957-2010), wyrażone w formie trendu liniowego. W pracy wykorzystano średnie miesięczne wartości temperatury wody w następujących miejscowościach: Świnoujście, Międzyzdroje, Kołobrzeg, Władysławowo, Hel oraz Gdynia.

W większości analizowanych stacji (oprócz Świnoujścia i Kołobrzegu) nastąpił wzrost średniej rocznej temperatury wody. Największy odnotowano w Gdyni, gdzie temperatura wody wzrastała średnio o około 0,02°C rocznie. Istotny statystycznie wzrost temperatury wody nastąpił w Międzyzdrojach w lutym, marcu, kwietniu i maju, w Kołobrzegu w styczniu i marcu, we Władysławowie w styczniu, lutym, marcu, kwietniu i w czerwcu, a w Helu i Gdyni w lutym, marcu, kwietniu, maju, lipcu i sierpniu. Największe zmiany następowały w kwietniu (w Helu i Gdyni powyżej 0,03°C rocznie). W Świnoujściu nie wystąpiły istotne zmiany temperatury wody z wyjątkiem niewielkiego jej spadku w czerwcu.